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INVENTORY OF FOREST AND RANGELAND AND DETECTION OF FOREST STRESS

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16. Abstract The final phases of this experiment are almost completed for all three sites in Georgia, Colorado, and South Dakota.

Computer processing from LARS, Purdue, of all three sites will be received by May 30, 1974 and compared for classification accuracy with our in-house computer classifications and also with photo interpretation of color composites.

Correcting for slope angle improved one Series category in Colorado, Ponderosa Pine Forest from 81, 57, and 33 percent correct recognition to 83, 73, and 80 percent (slopes were 0-15 degrees, 15-30 degrees, and greater than 30 degrees, respectively). Unfortunately, commission errors increased at the low and medium slope classes with improved recognition.

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TITLE: Inventory of Forest and Rangeland and Detection of Forest Stress

ERTS Proposal Number 226

Black Hills Test Site (Forest Stress) 226A

Coinvestigator: F. P. Weber

GSFC Identification Number AG-014

Principal Investigator - Robert C. Heller

STATEMENT OF PROBLEMS:

1. None

ACCOMPLISHMENTS DURING THE REPORTING PERIOD:

1. Infestation trend information for the mountain pine beetle in the Black Hills has been determined within three subblock study areas. Infestation data are based on a comparison of dead tree counts within each of the subblocks obtained by interpretation of 1:32,000-scale color infrared photography taken by the Forest Service September 8, 1972, and August 26, 1973. Individual tree counts were coded in six infestation size classes as shown below:

Infestation Size Code	Size in Meters
00	Less than 10
01	10 to 25
02	26 to 50
03	51 to 100
04	101 to 300
05	Greater than 300

Subblock 1, Savoy--Location: T.5N, R.2E, Sec. 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34

Area: 3,949.24 Hectares

Faders[1]

Infestation Size Code	1972	1973	Change
00	----	148	
01	2702	2653	
02	1198	1207	
03	1079	435	
04	715	845	
05	----	1050	
Total	5694	6338	1.11 to 1

Subblock 2, Englewood--Location: T.4N, R.3E, Sec. 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34
Area: 4,142.02 Hectares

Faders

Infestation Size Code	1972	1973	Change
00	----	276	
01	2552	6811	
02	252	3060	
03	----	870	
04	----	325	
05	----	----	
Total	2804	11342	4.04 to 1

Subblock 3, Long Draw--Location: T.4N, R.2E, Sec. 31, 32, 33, 34, T.3N, R.2E, Sec. 3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, and 18
Area: 4,087.49 Hectares

[1] Dead trees which appear straw-covered in August and early September.

Faders

Infestation Size Code	1972	1973	Change
00	----	218	
01	1583	3682	
02	81	1003	
03	----	609	
04	----	110	
05	----	----	
Total	1664	5622	3.38 to 1

1972 photo interpretation counts by E. H. Roberts
1973 photo interpretation counts by T. H. Waite

2. The Laboratory for Applications in Remote Sensing (LARS) at Purdue University has been working on an MSS processing subcontract since April 1, 1974. We have maintained communications on the processing effort by way of contract inspection trips at crucial intervals. As a result it was jointly decided to develop independent approaches to the analysis and mapping of each of the three test sites, depending on differing goals and differing vegetation cover types. Whereas a supervised processing and analysis approach, using training and test areas, was essential for Atlanta, this approach was not working well for Colorado; thus, a modified clustering routine was developed. At present we have received from LARS the following list of products:

a. Individual gray maps for each MSS channel and each site for all scenes.

b. Histograms and accompanying statistics for each MSS channel and each site for all scenes.

c. Cluster maps for Atlanta and the Black Hills at several levels.

d. A 35 mm color composite of the Lead block for scene 1028-17121.

The remaining products as specified in the contract will be delivered to our office in Berkeley by May 31, 1974.

We have worked out a procedure for checking the accuracy of the final classification for the two Black Hills scenes. Classification accuracy will be checked on the 1:24,000-scale geometrically corrected line printer output. Although scale-adjusted, color-coded classification maps will be produced, we doubt that they represent the best product for a quantitative evaluation of classification accuracy. Therefore, a six-line by six-column computer coordinate grid has been developed for systematically checking on classification. The coordinate intersection will define the center of a 3-by 3 -element cell with one-element buffer

surrounding for locational errors. Each cell with its buffer is being located on large-scale resource photography. If the cell and buffer fall on a cover-type boundary, that sample is disgarded. However, if the cell and buffer fall within pure type, the photo classification is compared to the computer classification. Using this procedure we hope to obtain about 2 percent of the samples which fall in a pure cover type. For the Lead block this would provide 440 cells for checking the accuracy of the LARS classification.

3. Human interpretation techniques for the two Black Hills blocks and the three subblocks have been finalized and trial interpretations made. Interpretations will be made on the large blocks (Lead--41,293 Hectares and Spearfish Canyon--35,648 Hectares) at a scale of 1:150,000 on the Bausch and Lomb Zoom 70 Stereoscope and the Variscan projection viewer. For the small subblocks (Savoy--3,949 Hectares, Englewood--4,142 Hectares, and Long Draw--4,088 Hectares) interpretations will be made at a scale of 1:70,000 on both the Zoom 70 and the Variscan viewer. In dealing with the large blocks the interpreters will classify points into the Black Hills ECOCLASS system whereas with the smaller subblocks they will draw a cover type map which will be checked for accuracy against the type maps drawn from the interpretation of the large-scale resource photography.

WORK PLANNED FOR THE NEXT REPORTING PERIOD:

1. Complete the MSS processing subcontract with Purdue and jointly evaluate classification results.

2. Complete the human interpretation of scene 1334-17124 with all three interpreters and determine accuracy for: (a) interpreters, (b) scale, and (c) interpretative aids.

3. Complete analysis of biophysical data transmitted via the DCS/DCP system, and provide a post experiment evaluation of the spectrometers.

SIGNIFICANT RESULTS:

We have not been able to identify mountain pine beetle infestation spots (stress) on ERTS-1 color composites in the Black Hills. We believe that the area which contains the largest infestations is much too complex spectrally (mixture of bare soil and rock, grassy pastures, hardwoods, dead and fallen pine, and scattered healthy pine) to identify the subtle color shift of the dead trees on a simulated color infrared composite. In the areas of less spectral confusion (subblock 2) the infestations are too small in size to be resolved on ERTS-1 imagery.

PUBLICATIONS: None

RECOMMENDATIONS FOR CHANGES: None

STANDING ORDER FORM CHANGES: None

ERTS IMAGE DESCRIPTOR FORMS: None

DATA REQUEST FORM CHANGES: None

TITLE: Inventory of Forest and Rangeland and Detection of Forest Stress

ERTS Proposal Number 226

Atlanta Test Site (Forest Inventory) 226B

Coinvestigator: Robert C. Aldrich

GSFC Identification Number AG-014

Principal Investigator - Robert C. Heller

STATEMENT OF PROBLEMS:

1. We are having no significant problems at this time.

ACCOMPLISHMENTS DURING THE REPORTING PERIOD:

1. The photo interpretation test to evaluate ERTS bulk photographic data for classifying forest land has been completed. Data for 293 random locations are being summarized and analyzed for the final report.

2. Computer maps stratifying six land-use classes have been produced for two 10,000-acre areas from CCT's for scene 1084-15440 (October 15, 1972) and scene 1264-15445 (April 13, 1973). An analysis of mapping accuracy and accuracy of land-use area estimates is underway and will be included in our final report.

3. A photo key to identify land-use classes on ERTS and high-altitude photography is nearing completion. Examples will be included in the final report.

4. Land classification being performed by LARS (Purdue) under contract to the PSW station is nearing completion. The final products will be delivered in early June. An analysis of mapping accuracy will be done at that time and the results compared with the products of our own "in-house" classification procedures.

WORK PLANNED FOR THE NEXT REPORTING PERIOD:

1. Data from human interpretation, and computer classification procedures (in-house and LARS) will be summarized, analyzed, and the results compared for inclusion in the ERTS final report.

2. The final ERTS report will be written and prepared for submission to NASA by August 9, 1974.

SIGNIFICANT RESULTS: None to report at this time.

PUBLICATIONS: None

RECOMMENDATIONS FOR CHANGES: None

STANDING ORDER FORM CHANGES: None

ERTS IMAGE DESCRIPTOR FORMS: None

DATA REQUEST FORM CHANGES: None

TITLE: Inventory of Forest and Rangeland and Detection of Forest Stress

ERTS Proposal Number 226

Manitou Test Site (Rangeland Inventory) 226C

Coinvestigator: Richard S. Driscoll

GSFC Identification Number AG-014

Principal Investigator: Robert C. Heller

STATEMENT OF PROBLEMS:

1. None. All retrospectively ordered and reordered data products have been received.

ACCOMPLISHMENTS DURING THE REPORTING PERIOD:

1. Driscoll presented a paper "ERTS-1 data for classifying native plant communities--Central Colorado," at the 9th International Symposium on Remote Sensing of Environment on April 17, 1974. This paper, co-authored with Richard E. Francis, Rocky Mountain Forest and Range Experiment Station, and Dr. James A. Smith and Roy A. Mead, Department of Earth Resources, Colorado State University, summarized the results of visual interpretation and machine processing of system corrected images (SYCI) of scene I. D. 1028-17135. Copies of the paper are attached.

2. Machine processing for interpretation to the Series level of one plant community class, Ponderosa Pine Forest, was initially improved by adjusting the apparent spectral signature to slope classes. Three slope classes with a southeast aspect, the aspect to correspond to the most direct illumination from the sun, were selected: 0-15 degrees (low), 15-30 degrees (medium), and greater than 30 degrees (high). The initial classification using a spectral signature from low slope points produced the following results for the Ponderosa Pine Series:

Slope Class	% Correct Recognition	% Commission Errors		
		DOUGF[1]	LDGPO[1]	SPFIR[1]
Low	81	10		7
Medium	57	10	4	16
High	33	16		14

[1] DOUGF = Douglas-Fir Series
LDGPO = Lodgepole Pine Series
SPFIR = Spruce/Fir Series

Regression equations were generated to relate mean spectral response in each of the four ERTS-1 MSS channels to slope class. The analysis, Gaussian likelihood classification, was then repeated by adjusting the mean vector of spectral response to the regression equations. The average covariance matrix for the medium slope class was used for all three slope classes to produce the following adjustment for the Ponderosa Series classification:

Slope Class	% Correct Recognition	% Commission Errors		
		DOUGF	LDGPO	SPFIR
Low	83	17		
Medium	73	14	3	2
High	80	10		2

It should be noted that although correct recognition of the Ponderosa Pine Series improved after signature adjustment, commission errors with the Douglas-Fir Series increased at the low and medium slope categories. The reason for this is not fully understood but could be related to the close association of the two Series in the natural landscape, as well as similarity of spectral response at the fringe of the established criteria for classifying the Series.

3. Visual interpretation has been completed for the SYCI color composite of scene I. D. 1028-17135 (August 20, 1972). Image descriptors have been developed for the SYCI color composites of scenes I. D. 1334-17142 (June 22, 1973) and I. D. 1388-17134 (August 15, 1973). An interpretation test using spot-sampling for the latter two scenes has been developed and one interpreter has completed the testing. Two other interpreters are working on the test.

4. Three interpreters have complete PI testing of ERTS support missions 205 and 211. Statistical analysis has been initiated using a 4-way fixed model ANOVA procedure to determine the effectiveness of these data for interpreting various categories of the ECOCLASS classification system.

5. Point sampling of apparent image density using the microdensitometer has been completed for the Forest Series classes. It is nearly complete for the Grassland Series. Statistical analyses using Student's "t" test comparisons for unequal sample sizes will be used to determine the effectiveness of image density sampling for classification of different categories under ECOCLASS.

WORK PLANNED FOR THE NEXT REPORTING PERIOD:

1. This is the last formal report prior to submitting the first iteration of our final report on August 9, 1974.

2. Francis will confer with LARS/Purdue regarding machine processing of part of SYCI scene 1388-17134.

3. All personnel, Driscoll, Francis, and two technicians, will complete all data analyses and write the report.

SIGNIFICANT RESULTS:

Correcting for slope angle improved machine interpretation for at least one Series category, Ponderosa Pine Forest, in the Colorado area. Prior to adjusting apparent spectral signatures for slope classes, correct recognition by machine processing was 81, 57, and 33 percent, respectively, for low (0-15 degrees), medium (15-30 degrees), and high (greater than 30 degrees) slopes. Adjusting for slope steepness, recognition improved to 83, 73, and 80 percent for the respective three slope classes. The commission errors between the Ponderosa Pine Series and Lodgepole and Spruce/Fir Series decreased among all slope classes. However, the commission errors between the Ponderosa Pine Series and Douglas-Fir Series increased at the low and medium slope classes. The reason for these latter errors is probably due to the close association of the two Series in the natural Colorado landscape and the strong similarity of apparent spectral response of closed canopy representatives of the two Series.

PUBLICATIONS:

Driscoll, Richard S., Francis, Richard E., Smith, James A., and Mead, Roy A. 1974. ERTS-1 data for classifying native plant communities--Central Colorado. 9th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. April 15-19, 1974.

RECOMMENDATIONS FOR CHANGE: None

STANDING ORDER FORM CHANGES: None

ERTS IMAGE DESCRIPTOR FORMS: 44 total submitted

DATA REQUEST FORM CHANGES: None

ERTS-I DATA FOR CLASSIFYING NATIVE PLANT COMMUNITIES--CENTRAL COLORADO[1/]

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ABSTRACT

Visual interpretation and machine processing of system corrected ERTS-I scene I.D. 1028-17135 of a central Colorado mountainous area provided similar results for classifying native plant communities to the Regional Level. Classification to the Series Level was not as successful. However, adjusting the apparent spectral signature to slope classes of the Ponderosa Pine Series initially improved classification of that Series using machine processing.

INTRODUCTION

ERTS-I imagery offers the natural resource land planner and manager unparallelled opportunity to examine landscape characteristics of large areas. However, to be fully useful, the first requisite is to know exactly what the sensors are "seeing" with regard to the natural vegetation. This paper discusses the effectiveness of visual interpretation of the system corrected color composite of an ERTS-I scene (1028-17135) and the machine processing of system corrected MSS digital data for the same scene to classify native plant community systems in the central Colorado area.

The non-urban, non-agricultural area in central Colorado is generally characterized by extreme diversity in plant community systems and extreme variations in topography. In general, the vegetation aligns itself to changes in elevation, but frequently terrain slope and aspect compensate for elevational differences. For example, ponderosa pine (*Pinus ponderosa*) forests occur mostly on ridges and slopes between 2,000 m and 2,700 m, but extend below this zone to 1,800 m and above the zone to 3,000 m depending on moisture and insolation. Grassland and other forest communities vary similarly.

The goods and services provided by the area are the traditional ones for western U.S. wildland areas: timber, grazing, water for commercial and domestic use, recreation in terms of hunting, fishing, and sight-seeing, and habitat for a myriad of animals. However, increasing pressure is being applied through recreational and permanent home developments and other human activities. The inventory and monitoring of the resources to assist in evaluating the impacts of human intervention is obviously important and must be done by some means other than ground survey alone. The way ERTS-I data can assist with this problem in central Colorado is being defined.

1/ Research supported in part by the NASA, ERTS-I program, Contract No. S-70251-AG.

THE STUDY AREA

The specific study area is located between 38°30' and 39°30' north latitude and 104°40' and 106°10' west longitude, and includes approximately 14,000 sq km (Fig. 1). The vegetation, topography, and geology of the study area are highly variable. The vegetation consists of a variety of coniferous forests ranging from approximately 1,900 m elevation above mean sea level to tree-line at approximately 3,500 m. These forests include: (1) ponderosa pine (Pinus ponderosa), (2) pinyon-juniper (Pinus edulis intermingled with species of Juniperus, mainly J. scopulorum), (3) Douglas-fir (Pseudotsuga menziesii var. glauca), (4) lodgepole pine (Pinus contorta), and (5) spruce/fir (primarily a mix of Picea engelmannii and Abies lasiocarpa). Intermingled throughout the area are deciduous forests of quaking aspen (Populus tremuloides). The tree canopy of these forests varies from very open to so dense that crowns nearly touch. The open tree stands permit the development of an extensive herbaceous understory. Where the forest canopy is closed, herbaceous plants are scarce.

Tree-free herbaceous parks, in which Arizona fescue (Festuca arizonica) and mountain muhley (Muhlenbergia montana) are the dominant grasses, occur in the lower elevational areas and are principally associated with the ponderosa pine forests. These grass dominants give way to other species of fescue (F. idahoensis and F. thurberiana) and oatgrass (Danthonia parryi) at higher elevations. Above the tree-line, in the Alpine, are a variety of herbaceous communities comprised of heterogeneous mixtures of low-growing grasses and forbs.

Within the central portion of the area is a large, nearly treeless area, South Park, which has supported ranching since about 1910. Due to past heavy grazing, this area now supports low-stature vegetation in which blue grama (Bouteloua gracilis) and slimstem muhley (M. filiculmis) are the most prominent grasses. These and associated species provide the aspect of a shortgrass prairie. Around the fringes of South Park, and in some places within the Park where the herbaceous communities interface with the forests, Mountain bunchgrass communities become prominent.

Wet-meadow and streambank communities are especially well developed in South Park. Various species of sedges (Carex sp.) and rushes (Juncus sp.) predominate in the more moist areas. Tufted hairgrass (Dechampsia caespitosa) mixed with species of bluegrass (Poa sp.) form communities in those areas that are not quite so moist. Throughout the area, generally in association with the meadows, are shrubby communities dominated by species of willow (Salix sp.).

Topographically, the main portion of the study area varies from approximately 2,150 m to 4,300 m above mean sea level. Altitudinal variations are dramatic, as much as 700 m per km in many places. The average elevation of South Park is approximately 2,750 m above mean sea level.

Geologically, the eastern portion of the area is associated with the Pikes Peak and Kenosha batholiths, and is comprised primarily of granitic mountains and outwash. The western portion is comprised of highly intruded sediments; the intrusions are primarily of granite or granite-gneiss material with some schists, trachyte and andesitic flows. These mountains have been highly dissected by glaciation, and glacial outwash is common within and around the mountains. The northern end is framed by the Kenosha batholith and other intrusive materials. The southern portion of the area is associated with the Arkansas Hills, and associated volcanos from which large andesitic lava flows have originated. Also associated with the southern portion are geologically old uplifted sediments. South Park, a large treeless peneplain, occurs in the west-central part of the area. However, igneous intrusions and flows are abundant throughout the Park (Weimer and Haun 1960).

Generally, the mountain ranges in the area are oriented along a north-south axis. However, many spur-fragments, as well as individual units within the major ranges, are oriented east-west. This presents a complex matrix of varying slope aspect relationships that not only influence the vegetation patterns but add to the complexity of processing and interpreting remotely sensed data, including that secured from platforms such as ERTS-I.

METHODS AND MATERIALS

This study used the system corrected, 24 cm, color composite and the corresponding system corrected MSS digital tapes of ERTS-I scene I.D. No. 1028-17135 dated August 20, 1972. This scene was selected because it included the first relatively cloud-free image of the study area, and was imaged at a time when most vegetation was just past peak growth. This does not necessarily mean that a scene selected at the time of maximum phenology is best for classifying the units of interest. Rather, it means that vegetation classes are exhibiting major morphological and reflectance differences which provide potentially increased probabilities for discrimination with a one-time scene. This phenomenon has been observed when dealing with large-scale aerial photographs (Driscoll and Coleman 1974).

Within the area, five subunits, approximately 576 sq km, were selected for intensive investigation (Fig. 2). These subunits were not necessarily replications; the vegetation classes in one unit were not completely represented in all other units. They were selected to include the variety of situations within the study area.

The hierarchical vegetation classification system used to test the effectiveness of the ERTS-I scene has been established according to ecological principals of polyclimax concepts (Daubenmire 1952) and is in current use by natural resource managers. This system is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken 1970). Five categories are defined, proceeding from the most general to the most specific. Descriptions of these categories are as follows:

Category	Definition
V - Formation:	The most general class of vegetation characterized by general appearance: grassland, coniferous forest, deciduous forest, etc.
IV - Region:	Groups of community systems with similar appearance and climatic controls: montane grasslands, temperate mesophytic (medium moisture requirements) coniferous forests, alpine grasslands.
III - Series:	A group of vegetation systems having common dominant climax species: ponderosa pine forests, lodgepole pine forests, fescue grasslands, wet herbaceous meadows.
II - Habitat Type:	The unit with relatively pure internal biotic and abiotic structure: ponderosa pine-Arizona fescue, thurber fescue-aspen fleabane. These are the elemental units of the plant community classification scheme upon which management is based. Frequently related to "climax" situations or situations in a high successional level "held" in a relatively stable state by proper management.
I - Community Type:	Systems that appear relatively stable under management, and may be frequently equivalent to the habitat type. Usually the biotic components are dissimilar, but abiotic components analogous to habitat type.

Three Regional and 12 Series categories were initially established for this study. These were as follows:

Region:

1. Coniferous forest
2. Deciduous forest
3. Grasslands

Series:

Forest:

1. Ponderosa Pine
2. Spruce/Fir
3. Douglas-fir
4. Lodgepole Pine
5. Pinyon Pine
6. Aspen

Shrub:

1. Willow
2. Oak

Grassland:

1. Shortgrass
2. Mountain Bunchgrass
3. Wet Meadow
4. Dry Meadow

Due to loss of sampling points subsequently described, or small sample size after establishing the five subunits, three of the Series categories--Pinyon Pine, Oak, and Dry Meadow--were omitted from this study. In addition, the Willow class was not included in machine processing. Subsequent analyses and results are based on the remaining classes. The visual and machine interpretations were independent to eliminate a source of bias in the results.

Visual Interpretation

Vegetation maps, topographic maps, support aerial photographs exposed at nearly the same time as the ERTS-I scene, and ground survey were used to establish sample cells for visual interpretation. The sample cells were initially selected and plotted on the vegetation type maps to represent a piece of landscape approximately 500 m square. The size of data cell selected was determined by two factors: the originally advertised resolution and geographic fidelity of the bulk MSS products, and expected error both in the satellite and data collection system and in transferring sample cells from maps to the ERTS-I scene. A 10 percent sample of these cells was field-verified using the aerial photographs and ground survey. Since only two of these field-verified cells required reclassification, and this a change from one coniferous forest type to another, it was decided that the remaining classifications were acceptably accurate for the study.

No fewer than 20 sample cells were selected for each category with one exception. The Willow Series included only four cells due to limited distribution and areal extent. Most of the Willow Series occurred with a lineal dimension such that would not fit the sample cell size. A total of 660 cells were used for training and testing the visual interpretability of the ERTS-I frame.

Transparent overlays were constructed showing cell locations for the total study area and each of the five subunits (Fig. 3). The Universal Transverse Mercator (UTM) coordinate representing the location of each cell was precision plotted to a scale of 1:100,000. These overlays were then photographically reduced on 0.004 mil. clear film positive material to the 1:1,000,000 scale matching the 24 cm ERTS-I color composite. The plotted cell size at this scale represented a piece of landscape 900 m square to minimize edge-effect of cell-wall lines. In addition, selected major UTM coordinates were plotted to assist in positional location on the ERTS-I frame.

Image descriptors were determined for all categories, except one, using at least 10 known examples for each category. The one exception was the Willow Series for which two of the cell samples were used. Color, the primary descriptor used, was standardized by reference to the ISCC-NBS standard color codes. Subsequent interpreters of the ERTS-I frame had access to image descriptors and training sets for reference, but they had no prior knowledge of the content of the test

cells except from possible on-the-ground knowledge of the area. All interpretation was done on the 24 cm ERTS-I frame using 3X to 7X magnification.

Machine Processing

As an adjunct to the photographic interpretation of the ERTS color composite, the system corrected MSS digital data representing the same scene was processed by computer. Representative sample plots for Region and Series vegetation categories were selected from two of the subunits by the process described below. Supervised and unsupervised classification techniques were applied, but only the supervised classification results are reported here.

Several difficulties arose in the direct application of computer recognition methods to the system corrected MSS data. These included the difficulty of accurately locating training areas for vegetation classes, and the variation in spectral response apparently due to topographic relief effects on spectral signatures. In contrast to highly cultivated areas, it was difficult to detect road or field boundaries in ERTS imagery for mountainous terrain. To apply machine processing to the vegetation classes such as those represented in the two subunits, where they occurred either in small areas compared with the ERTS resolution or heterogeneously, the authors have recently incorporated image correction and registration programs. These programs permit easier transfer of ground truth information to the data (Anuta 1973). In addition to supervised classification results, the variation of spectral response with slope for one vegetation series, Ponderosa Pine, was determined.

Selection of sites for computer processing

Topographic maps at 1:24,000 scale, vegetation type maps, and small-scale (1:100,000) aerial photographs were used to select and delineate representative training sets for the different vegetation classes. Vegetation Series included were Mountain Bunchgrass, Shortgrass, Wet Meadow, Douglas-fir, Ponderosa Pine, Lodgepole Pine, Spruce/Fir, and Aspen. In addition, training areas for water, clouds, and cloud shadows were determined.

A hard-copy image mosaic of approximately 1:90,000 scale for the test subunits was generated using the microfilm image capability of the CDC 6400 computer. Individual density levels of this mosaic were generated by illuminating varying numbers of dots in a grid pattern. The overall effect is the same as that produced by an image halftone in newspaper print. Traditional photointerpretation techniques were then applied to this mosaic to locate training sets. Cartesian coordinates of the corners of rectangular areas chosen to represent each class were determined by magnification of the hard-copy mosaic so that individual resolution elements could be counted. The size of these training sets varied, depending on the natural meandering of the boundaries of the class categories.

In addition to the training fields for each class category, nine fields of equal area representing Ponderosa Pine Forest Series were originally identified on the basis of slope steepness and tree crown closure. A single field was selected for each of three levels of slope and three levels of density. The three levels of slope steepness were approximately 0 to 15 degrees (low), 15 to 30 degrees (medium), and greater than 30 degrees (high) as determined from the topographic maps. The tree crown closure levels were quantitatively determined by photointerpretation. Approximate ranges were 0 to 25 percent, 25 to 60 percent, and greater than 60 percent closure.

Computer classification

Supervised classification of vegetation categories was done using a maximum likelihood criteria assuming multivariate Gaussian densities. The basic program employed was RECOG (Smith et al. 1972), a multiphase program patterned after the Purdue LARSYS approach (Purdue University 1968). Image mosaics, mean vectors and covariance matrices, and channel selection were generated using various phases of this program. The original divergence criteria were employed for channel selection. In generating recognition tables for training sets, no thresholding was employed; each ground resolution element was forced into one of the 11 categories.

Unsupervised classification was attempted for selected subsets of the test areas using CLUSTD, a program developed at NASA/JSC (Haskell 1973). This program utilizes a sequential scan-line algorithm employing a correlation measure between data vectors. The program is particularly effective for large-dimension feature vectors. The unsupervised approach avoids the difficulty of initially selecting training areas, and is useful for vegetation regions that are heterogeneously mixed. However, problems arose in validating and assigning category names to the clusters generated because of digital image distortion and diversified terrain. Therefore, specific results are not included here. Further analysis using this method in conjunction with image correction programs is continuing, however.

Spectral signature variation

To investigate the effect of topography and tree crown cover on classication performance, mean spectral response and covariance matrices were determined for nine slope/canopy Ponderosa Pine classes previously described. In subsequent data checking, a high slope-high density plot had to be eliminated since it was discovered to represent a bare soil area. Consequently, in further analysis, eight of the Ponderosa classes were utilized. Standard statistical t and F analyses indicated a significant relationship between spectral response and slope, but no obvious trend between spectral response and tree crown closure. The mean spectral response in each channel was plotted (Fig. 4) as a function of slope category where 1 = low slope, 2 = medium slope, and 3 = high slope. Except for category 3, high slope, there are three points per slope range corresponding to three different density variations. In all channels, there is a clear trend of increasing response with increasing slope. A linear regression line was thus determined for each spectral channel to represent this trend (Fig. 4).

Gaussian likelihood classification was performed on the eight Ponderosa Pine subsets. The classification was done using a spectral signature derived from one of the low-slope plots. Original training statistics for the other Ponderosa Pine Series vegetation categories were also employed. Regression equations (Fig. 4) were generated to relate mean spectral response in each channel to slope category. The analysis was then repeated by adjusting the mean vector of spectral response to the regression equations. It is not clear how to adjust the covariance matrix according to scene environmental changes (Smith and Oliver 1974, Kriegler and Horwitz 1973). In the present study, the average covariance matrix for the medium slope category was used for all three slope ranges.

RESULTS AND DISCUSSION

Visual Interpretation

Interpretation to the Regional category for the ECOCLASS vegetation classification hierarchy was successful (Table 1). There were no commission errors of interpreting to either the Coniferous or Deciduous Forest Regions in the central Colorado area. Since the characteristics of this class category are general, that is either Coniferous Forest or Deciduous Forest, the apparent spectral response recorded by the ERTS-I MSS sensors should be sufficiently discrete to allow visual (manual) interpretation of these vegetation systems in temperate regions. This assumes that the imagery is exposed during the time of maximum phenological difference; during the summer growing season when the vegetation is at maximum growth.

There was a 6 percent commission error in classifying the Grassland Regional category of the August ERTS-I color composite by the visual interpretation process. These errors were committed where the Wet Meadow Grassland Series occurred adjacent to the Aspen Forest Series. The image signatures, especially color, were so similar that interpreters were confused between the two categories unless they could determine topography by use of associated evidence surrounding the sample test cell. Usually, the interpreter could relate to topography, especially if he was knowledgeable about the area, and if the test cell occurred on an apparent slope, it was classified as Aspen (Deciduous Forest Region). The errors were committed when the two classes occurred on apparently level relief.

Visual interpretation to the Series level was not as clearly definitive unless an apparent high scene contrast existed between the classes of interest. In the case of the Forest Series classes, none of the test cells were classified correctly better than 67 percent of the time (Table 2). The commission errors for the Aspen Series occurred mostly with the Ponderosa Pine Series and to some extent with the Douglas-fir and Spruce/Fir Series. The Aspen stands, which do occur as a monoculture in the test site, also frequently occur in conjunction with the Coniferous Forest Series; the individual trees intermix in varying amounts. The threshold at which the spectral response of one class appears to override that of the other when the two intermix has not yet been isolated.

The Douglas-fir Series was confused with the Ponderosa Pine and Spruce/Fir Series primarily because the three classes frequently occur intermixed, both as relatively pure stands and mixed stands of the Series. The major errors were misclassification of test cells in which tree crown canopy closure was nearly solid for all three classes, or one class occurred on a reverse slope in relation to sun angle, and mountain shadow effects produced an apparent image signature similar to some other class.

The Lodgepole Pine Series was misclassified for the Douglas-fir and Spruce/Fir Series. These errors were also related to misinterpreting test cells in which tree canopy closure was nearly complete or the Series intermixed. The Spruce/Fir Series was primarily mistaken for the Aspen Series. The reason for this is not fully understood, but these misclassifications were also related to species mixing in the test cell examples.

The Ponderosa Pine Series was the most misclassified Forest Series class. It was confused primarily with the Douglas-fir Series. Stand examples of these Series within the study area frequently occur on alternate south and north slopes, respectively. In addition, each Series occurs on both slopes as well as ridgetops, depending on elevation and slope steepness. Also, both Series classes occur naturally with relatively open and nearly closed crown canopies. However, those Ponderosa Pine Series test cells which occurred on relatively flat terrain (<20 degrees slope) were correctly classified about 85 percent of the time.

It became apparent during the visual interpretation testing that, in addition to the previously mentioned interpretation problems, slope angle and aspect in relation to sun azimuth were significantly affecting the apparent spectral response of the scene. These effects could not be determined by visual interpretation since individual ERTS resolution elements could not be observed and chance of error in interpreting slope and aspect were great. Therefore, the initial assignment of the effects was isolated by digital tape processing and is discussed in the next section, Machine Processing.

Visual interpretation of the Shrub and Grassland categories to the Series level was more definitive, especially where apparent scene contrast was high (Table 3). The Willow Shrub Series, which occurs in areas with water tables near the ground surface and in association with dense stands of other water-loving vegetation, was classified 100 percent correctly. However, some of the Wet Meadow Series, which were vegetationally similar to the Willow Shrub Series exclusive of the willow component, were misidentified as the Willow Series. This was probably due to interpreters' knowledge of the area; they were quite certain where Willow Series occurred, but not so certain where the Meadow Series were in relation to the Willow Series.

The Mountain Bunchgrass Series was severely misinterpreted. Commission errors occurred primarily with the Shortgrass Series and to some extent with the Wet Meadow Series, due primarily to the location of test cells in apparent transition areas. Interpretation of the mesophytic Grassland Series, Mountain Bunchgrass and Shortgrass, appears confounded by the relative amounts of live plant foliage cover, amount of plant litter, and amount and kind of bare soil in the scene as these components affect the image signature. For example, areas which color coded to gray purplish red according to the ISCC-NBS standards have live plant foliage cover ranging from 25 to 55 percent. Conversely, grasslands with similar vegetation structure, but different soil surface conditions, code to different colors. The problem of determining the effects of different mixes of these components on image signatures in relation to sensor elevation is being

investigated. It appears now that live herbaceous foliage cover, in excess of approximately 30 percent in the same Series type, is necessary before the characteristic pink color of live vegetation manifests in ERTS-I color composites exposed in August in areas like the central Colorado mountainous region.

Machine Processing

Computer classification was applied to both Region and Series vegetation categories (Table 4). All four spectral channels were employed for classification of these units. Individually, it was found that MSS band 6 represented the best single channel, MSS bands 5 and 7 the best two, and MSS bands 5, 6, and 7 the best three. However, negligible computer cost was involved in employing all four spectral bands. For machine interpretation, it was necessary to include additional categories: water and cloud or cloud shadow as compared to Grassland, Coniferous Forest, or Deciduous Forest. At the Region level there is little confusion between categories except for some commission errors between Coniferous and Deciduous Forests (Aspen). At the Series level, the Grassland and Deciduous Series remained well-separated from water, cloud, and cloud shadow.

Separation among Coniferous Series becomes difficult. These results are indicated in Table 5 for training sets. Within Coniferous Series classes poor results are obtained for Spruce/Fir, Ponderosa Pine, and Douglas-fir. Because these initial conclusions are based on training data only, the actual accuracy figures may vary with subsequent processing. The trends are clearly indicative, however, and have been used to guide further detailed processing. Recognition displays for the entire test areas have been generated and are currently being evaluated.

In an effort to understand the difficulties in separation among the Coniferous Forest Series, the Ponderosa Pine Series was studied in depth. Spectral response variations with both slope and tree crown cover were determined. Variation with slope was found to be particularly significant and a linear model was constructed to describe this relation. The following four equations were determined for the individual ERTS spectral channels:

$$Y_4 = 20.16 + 1.38 X$$

$$Y_5 = 16.39 + 1.79 X$$

$$Y_6 = 24.62 + 1.87 X$$

$$Y_7 = 12.77 + 1.26 X$$

where Y_i represents the relative spectral radiance in band$_i$ as recorded by the ERTS multispectral scanner and X is the slope category 1, 2, or 3.

Classification accuracies obtained for the eight Ponderosa Pine Series variants employing the original spectral signatures utilized in the Series classification task are given in Table 6. In general, the classification performance decreases and commission errors between Coniferous Series increases as slope increases. This trend is an indication, at least for the Ponderosa Pine Series, that spectral signatures derived from one slope range will not extrapolate to all slopes. After adjustment of the means according to the equations and using the average covariance matrix for the medium slope category, classification performance increased and commission errors decreased (Table 7). At present we have not isolated the factors that caused the spectral data to vary with slope or determined if these variations will continue for test Ponderosa Pine Series not used to generate the regressions equations. Several hypotheses relating projected areas of the Ponderosa Pine Series, understory conditions, and slope-sun angle relationships are being investigated. Computer programs for determining mean slope from contour maps are being used to increase the number of slope categories. These programs also eliminate human bias in interpreting the topographic sheets for slope values. The initial lack of direct correlation between varying vegetation cover and spectral response is not presently understood.

CONCLUSIONS

ERTS-I color composites and corresponding MSS digital tapes of the central Colorado mountainous area, exposed in August, can be used successfully to classify native plant communities to the Regional level of the ECOCLASS hierarchical classification scheme. The Regional category groups plant community systems that have similar external appearances and are under similar climatic controls. Examples of Regional classes are Coniferous Forests, Deciduous Forests, and Montane Grasslands.

Communities cannot yet be classified to the Series level in the hierarchy at an acceptable level of accuracy. Series level classes represented in the Colorado area include such groupings as Ponderosa Pine Coniferous Forests, Lodgepole Pine Coniferous Forests, Aspen Deciduous Forests, Mountain Bunchgrass, and Wet Herbaceous Meadows. Improvement in classification at the Series level by machine processing can be expected provided effects of slope steepness and aspect in relation to sun angle and sensor location are considered. Classification should also be improved if the effects of different mixes of live plant foliage cover, plant litter, and kind of bare soil surface on spectral signatures are determined. We are currently attempting to determine these effects.

Classifications to the Habitat Type level in the hierarchy will not be attempted until classification accuracy can be improved at the Series level. The Habitat Type is that level of classification in which internal biotic and abiotic structure is similar. It represents the elemental unit of plant community classification upon which land use and management is based.

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TABLE I. CORRECT VISUAL IDENTIFICATION AND COMMISSION ERRORS BY VEGETATION REGION FOR ERTS-1: 1028-17135

Vegetation Region	Correct ID (%)	Commission Errors (%)
Forest	100	0
Grassland	94	6

TABLE II. CORRECT VISUAL IDENTIFICATION AND COMMISSION ERRORS BY FOREST VEGETATION SERIES FOR ERTS-1: 1028-17135

Vegetation Region	Correct ID (%)	Commission Errors (%)				
		A	DF	LP	PP	SF
Aspen	64		7		21	7
Douglas-Fir	67				14	19
Lodgepole Pine	67		22			22
Ponderosa Pine	60		37	3		
Spruce/Fir	63	25	6	6		

TABLE III. CORRECT VISUAL IDENTIFICATION AND COMMISSION ERRORS BY GRASSLAND VEGETATION SERIES FOR ERTS-1: 1028-17135

Vegetation Series	Correct ID (%)	Commission Errors (%)			
		MBG	SG	WM	WWM
Mountain Bunchgrass	50		38	13	
Shortgrass	81	19			
Wet Meadow	78				22
Wet Willow Meadow	100				

TABLE IV. REGION COMPUTER RECOGNITION RESULTS ON TRAINING SETS

Vegetation Region	Correct Recognition (%)	Commission Errors (%) W	C	GR	CF	DF
Water	100					
Cloud/Cld. Shadow	97				3	
Grassland	100					
Coniferous Forest	94	1		3		2
Deciduous Forest	83				17	

TABLE V. SERIES COMPUTER RECOGNITION RESULTS ON CATEGORY TRAINING SETS

Vegetation Series	Correct Recognition (%)	Commission Errors (%) C	CS	W	BG	SG	WM	DF	PP	LP	SF	A
Cloud	100											
Cloud Shadow	94									5		
Water	100											
Bunchgrass	93					2	3					
Shortgrass	99	1										
Wet Meadow	88				12							
Douglas-fir	55			2					29	3	8	3
Ponderosa Pine	75							16		8	1	
Lodgepole Pine	92							2	2		5	
Spruce/Fir	16		1		5		4	17	1	48		8
Aspen	83							10			7	

TABLE VI. COMPUTER RECOGNITION OF PONDEROSA SITES FOR THREE SLOPE CATEGORIES

Slope Category	% Correct	Commission Errors (%)		
		DF	LP	SF
Low	81	10		7
Medium	57	10	4	16
High	33	16		14

TABLE VII. RECOGNITION RESULTS FOR PONDEROSA SITES AFTER SIGNATURE ADJUSTMENT

Slope Category	% Correct	Commission Errors (%)		
		DF	LP	SF
Low	83	17		
Medium	73	14	3	2
High	80	10		2

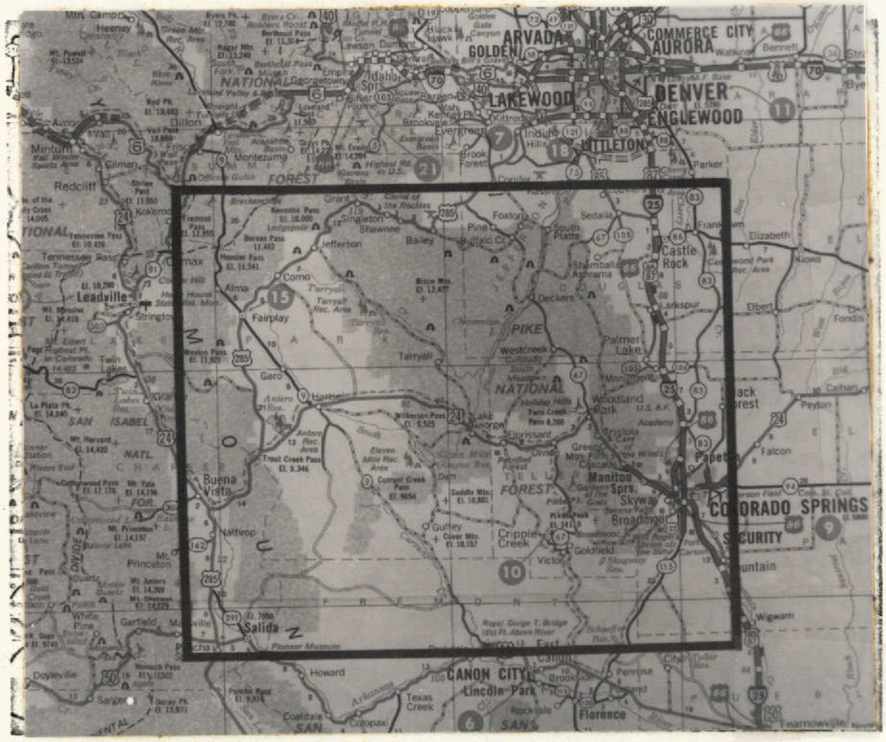

FIGURE 1. MAP LOCATION OF THE CENTRAL COLORADO AREA. The area is located west of Colorado Springs and includes part of the Front Range, a large high mountain park, and on the west, part of the Park Range.

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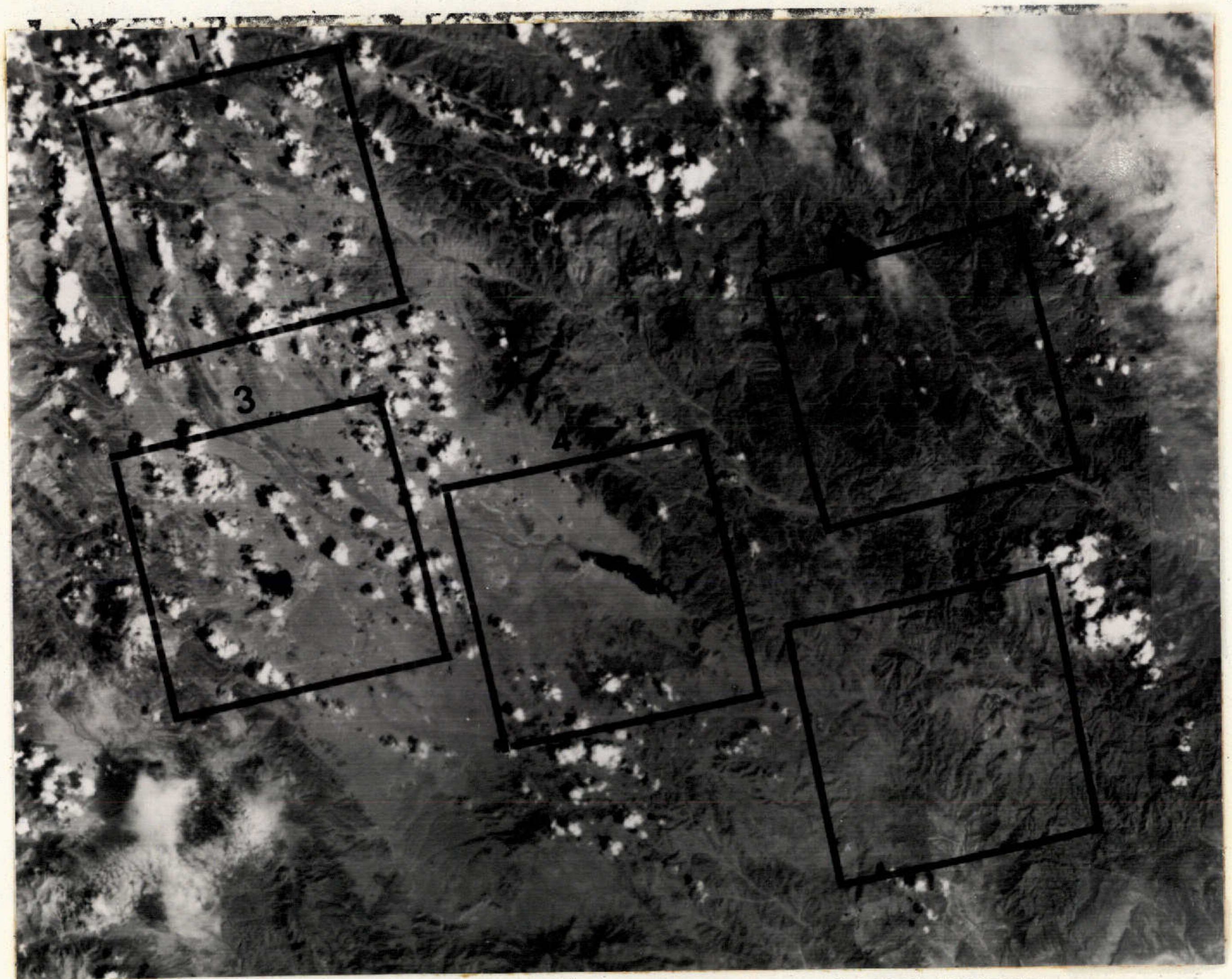

FIGURE 2. FIVE SUBUNITS WITHIN ERTS-1 FRAME 1028-17135 SELECTED FOR INTENSIVE INVESTIGATION. Pikes Peak occurs at the north-east corner of block 5. This is a black and white rendition of the ERTS-1 color composite which was made by combining MSS channels 4, 5, and 6.

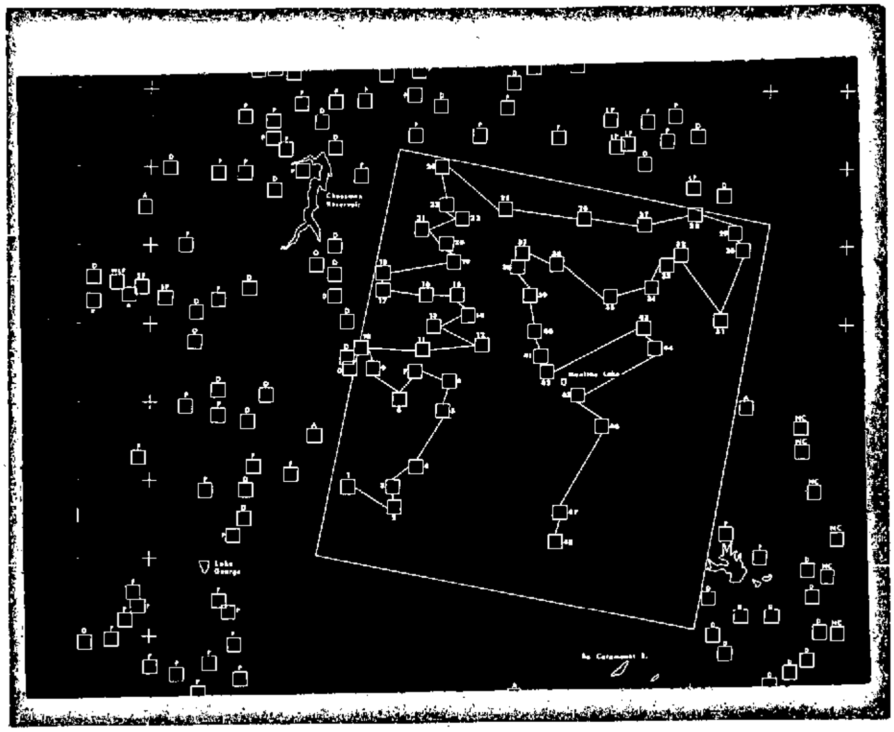

FIGURE 3. GRAPHIC REPRESENTATION OF TRAINING AND TESTING SAMPLE CELLS USED FOR VISUAL INTERPRETATION. Each small square represents an area of landscape approximately 900 m square. The interpreters concentrated on the center of the square and named the class-category they believed was represented by that signature.

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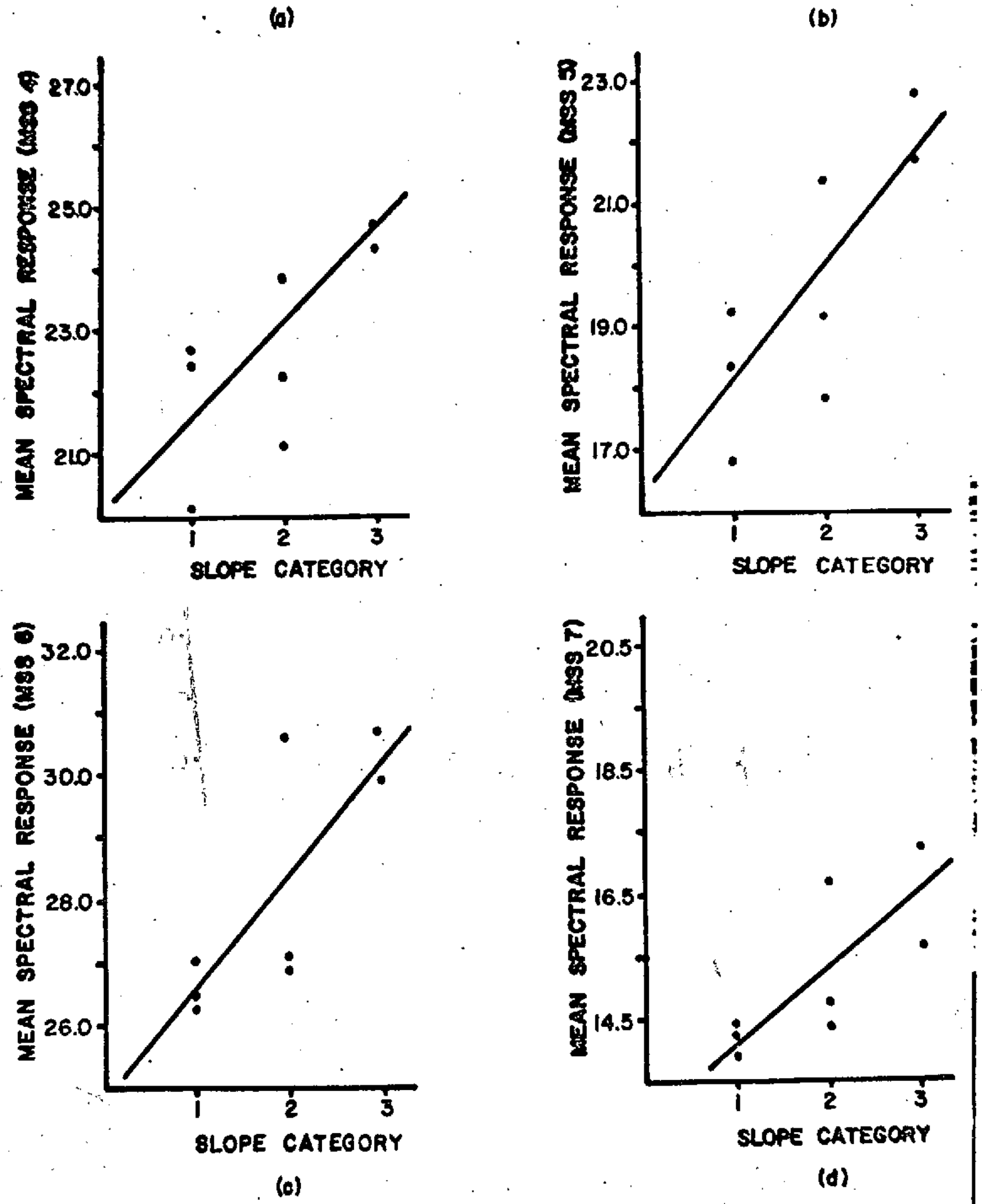

FIGURE 4. GRAPHIC REPRESENTATION OF THE MEAN SPECTRAL RESPONSE OF A PONDEROSA PINE SERIES BY SLOPE CLASSES. As slope steepness increases in relation to sun position and sensor location, spectral response increases. Adjustment of spectral means and use of average covariance corresponding to medium slope provided initial improvement for classifying the Ponderosa Pine Series.

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